Evaluation of Bulk Seed Handling Systems on Soybean Quality and Germination Rates

A Thesis submitted for partial fulfillment
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Abstract

There is no significant data on the interaction between soybean seed health and the handling mechanism used to transport the seed from a bulk storage container to the seed planter implement. Specifically, little is known regarding the effect of transportation systems on soybean germination rate and overall seed vigor. With approximately 200,000 seeds planted per acre (Wellman, 2006) on 75 million acres in the United States (NASS, 2006), the potential economic loss incurred by damage during transport is enormous. Testing the effects of different transport systems and various conditions of each transport system on the germination and vigor of seeds will identify the best system and system conditions for seed germination and seedling vitality.

This project shows that transport systems and the operating conditions of each affect soybean seed germination rates. The tests did not show a consistent statistical difference across all treatments, but showed a trend in the means as well as indications of higher operating speeds causing increased damage. Further testing needs to be conducted with larger samples sizes or numbers to further quantify the results.

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I would like to thank those that assisted with the completion of this project. Special thanks go to Matt Darr for the use of his lab space and all his work in coordinating the acquisition of materials and equipment. Thanks to Andy Evans and Mark Bennet for their assistance in the germination testing and use of their lab space. Additionally I would like to thank Carl Cooper for his assistance in fabricating test equipment as well as the entire Food, Agricultural, and Biological Engineering department for the use of their resources and equipment.

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Chapter 1

Introduction

1.1 Soybeans and the Agricultural Industry

Soybeans are a Southeast Asian annual leguminous plant *(Glycine max).* Approximately 75 million acres of soybeans are planted every year in the United States (NASS, 2006). The seeds produced by the soybean plant are used in many different industries and have many uses and benefits. In recent years the use of soybeans in the production of Bio-diesel has greatly increased and may continue to increase the demand for soybeans. Typical planting rates for soybeans are around 200,000 seeds per acre. The number of seeds planted per acre in conjunction with the number of acres planted yearly makes the need for efficient equipment imperative.

1.2 Motivation

Trends in the agricultural industry have been changing from that of small scale family operated farms to large corporate farming operations. Changes in farm size have created a change in the size and type of equipment used in the process of transporting soybean seeds from bulk storage into planting equipment.

The variety of transport equipment that is available commercially provides farmers with a range of choices for the type of transport system their operation will use. There has been no official published material comparing the effects of common transport systems on seed quality and germination of soybean seeds. The lack of information coupled with the large quantity of soybean seeds planted every year is driving this research.

1.3 Grain Drills and Air Seeders

Many farmers today are using larger planting devices. The two most common types of soybean planting devices are box drills and air seeders. Both drills and air seeders require that soybean seed be placed into a hopper for temporary holding until the individual seeds are placed in the ground. The location of the hopper with respect to the ground makes it necessary for a transport system to move the seeds into the planting device.

1.3.1 Grain Drills

A typical box drill would require elevating the seed to a height of approximately seven feet in order to place it in the hopper. The hopper would then hold approximately 50 bushels of seed. In order to better facilitate filling the hopper quickly and easily a transport system is used to move the seed from storage into the drill.

Figure 1.1 Box Drill

1.3.2 Air Seeders

Air seeders are another type of planting device that have become popular in recent years. Air seeders are typically taller than box drills at 12 to 15 feet tall. The seeder will also typically carry around 70 to 100 bushels of seed. Again various transport systems are used to fill the hopper on the air seeder.

Figure 1.2 Air Seeder

1.4 Bulk Transport Systems

There are two common types of transport systems used to transfer soybean seeds to a drill or air seeder. They are belt conveyors and augers. There are several different types of belts and augers that are used. Differences in size, shape, material, and operating conditions are the primary differences in the transport systems.

1.4.1 Belt Conveyor

Belt conveyors work by placing the seed on top of the belt and then running the belt along a controlled path. Belt conveyors come in a variety of types. There are flat belts with and without paddles as well as belts that are partially rolled into a tube while operating. The speed of the belt can also be adjusted depending on the application. Typical belt speeds are around 5-8 linear feet per second, conveying 10-15 bushels per minute.

Figure 1.3 Belt Conveyor System

1.4.2 Augers

Augers consist of a screw inside of an enclosed tube. As the screw turns, the seed progresses along the tube until it reaches the other end of the tube where it is discharged. The material used for the tube and the screw can be chosen by the consumer. The tube is typically made of plastic or steel. The auger can be steel, plastic, or a steel core with plastic bristles on the end of the flighting. Depending on the flighting material, augers typically operate in the range of 500-700 revolutions per minute, while moving 10-15 bushels per minute.

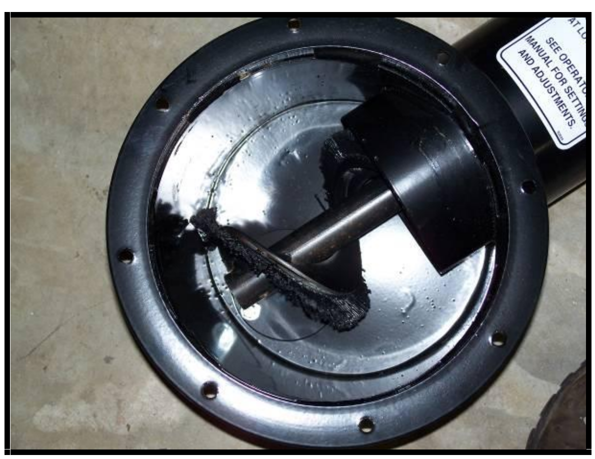

Figure 1.4 Auger in Tube

Figure 1.5 Brush Auger

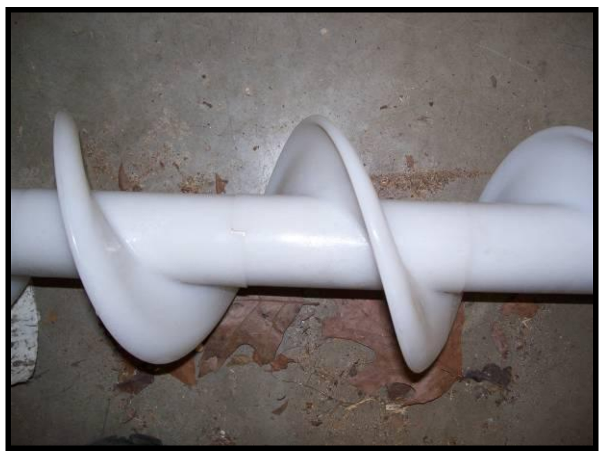

Figure 1.6 Plastic Cupped Auger

Figure 1.7 Steel Auger

1.5 Soybean Seed Packaging

Soybean seeds come in a variety package types. Soybeans can be kept in a grain storage facility and be placed directly into a hopper wagon. When purchased commercially seeds typically come in a 50 pound paper bag or in a large plastic container (50 bushels).

1.5.1 On farm Storage

Seed stored on farm from year to year is typically stored in a grain bin or in a building and then transported to a hopper wagon or grain truck for further distribution to the box drill or air seeder.

Figure 1.8 On Farm Grain Storage

1.5.2 Bagged Soybean Seed

Seed can be bought in bag units. Bag units typically weigh 50 pounds and must be unloaded by hand. The bags can be dumped directly into a drill or air seeder or can be dumped into the inlet hopper of a transport system.

Figure 1.9 Soybean Seed Bag

1.5.3 Plastic Bulk Storage

Soybean seed can be purchased in large plastic bins or plastic bags. Bins and bags typically hold 50 bushels of seed. The containers then must be lifted and poured into a transport system or directly into a planting device.

Figure 1.10 Bulk Storage Containers

1.6 Soybean Seed Variety

Soybeans come in different varieties and seed sizes. Seed varieties can include different genetic traits as well as different seed size and shape. Seed variety is carefully monitored and graded and is then labeled with a seed tag to ensure that consumers are aware of the relevant information concerning the seed size, variety, genetic traits, and herbicide tolerances. All soybean seeds are tested prior to being sold and must posses a minimum 90% rate of successful warm germination.

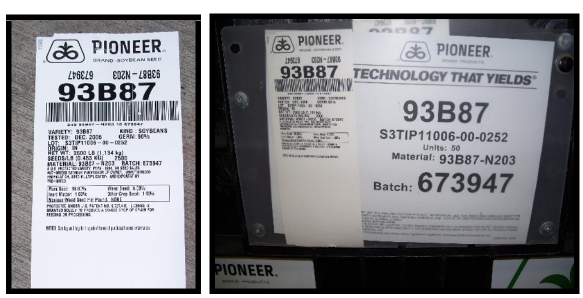

Figure 1.11 Soybean Seed Tag

Chapter 2

Literature Review

2.1 Seed Damage

Soybean seed is easily damaged both externally, as splits and cracks, and also internally. The damage can be caused by a variety of factors including; mechanical damage from an auger, impact from mechanical transport, heat damage, and disease. Seed damage is reflected in poor germination or no germination or as reduced yield because the plant can not grow and function as it should.

2.2 Causes of Damage

Damage to soybean seeds can come from a variety of sources. Physical damage to seeds can be caused by the harvesting mechanism. When the seeds are removed from the plants at maturity the seeds pass through a series of mechanical machines to separate them from the rest of the plant. Seeds can also be damaged by transport equipment. Transport systems can smash, cut, and impact seeds causing them to crush, split, or shatter. Additionally, there can be damage to seeds from disease, fungus, and genetic mutations and anomalies.

2.2.1 Impact Damage

Impact damage to soybeans is caused when a seed is dropped or flung at a high rate of speed and abruptly strikes a hard surface. Research has shown that impact damage can seriously affect soybean seeds. The speed of the seed as well as the temperature and moisture content of the seed are related to the amount of damage that is seen by the seed.

2.2.2 Crush Damage

Soybean seeds may be crushed by the mechanical handling equipment that is used to clean, sort, and transport the seeds. Most transport systems allow for seed to be trapped between a wall and another moving part of the machine. The two surfaces can then exert enough pressure on the seed to cause it to break or become compacted and damaged.

2.2.3 Disease Damage

Soybean seeds can be damaged by diseases and fungi. Soybean seed damage by disease and fungi is typically related to poor storage techniques or wet field conditions. Seeds that retain a moisture content higher than around 12.5 % for an extended period of time will tend to be more susceptible to disease and fungal invasion. Proper storage techniques must be employed to keep seeds from becoming infected.

2.2.4 Physical Damage

Physical damage is when seeds are either cracked, split, or crushed resulting in a change in the physical shape of the seed. External damage, such as splits and crushing, can be identified visually.

Figure 2.1 Physical Damage to Soybeans

2.2.5 Internal Damage

Seeds can be damaged internally as well as externally. A seed can be bruised on the inside without showing any external signs of damage. Internal damage can be caused in the same way external damage is through mechanical handling. Seeds can also be diseased without it being visibly recognizable.

Figure 2.2 Diseased Soybean Seed

Chapter 3

Treatments

3.1 Treatment Objective

The object of this project was to determine how the different transport systems affect seed quality and germination. In order to isolate the transport system all other variables were held constant.

The goal was to test for a difference in germination rates caused by the type of transport system used and then to test different conditions for each transport system.

3.2 Transport Systems

This research will use four different bulk transport systems. These systems include Unverferth:

- 16’ Brush auger, 6” diameter steel tube
- 16’ Steel auger, 6” diameter steel tube
- 16’ Plastic cupped auger, 6” diameter steel tube
- 18’ Rubber paddled belt conveyor, 6” diameter steel tube

3.3 System Parameters

In order to keep the treatments as consistent as possible as many variables as possible were held constant.

- Seed variety
- Seed size
- Seed moisture content (12.4%)
- Room temperature (68^{o} Fahrenheit)
- Seed temperature (68^{o} Fahrenheit)

- Room relative humidity (30%)
- Mass flow rate at inlet
  - System was calibrated to allow the mass flow of soybeans to be adjusted. Settings were determined for 4.5, 10, and 12.5 bushels per minute.
- Inlet drop height
- Transport system angle of elevation
  - 35^o from the horizontal
- Transport system operating speed
- Collection device
  - Samples were collected in a plastic container
- Seed drop height
  - 3 feet to collection device

3.4 Treatments

Five repetitions were taken for each of the treatments of the combination of manufacturer recommended flow and manufacturer recommended speed. Four repetitions were taken on the remainder of the treatments. Control samples were also pulled directly from the ProBox©.

Augers
- Recommended flow – 10 bushels per minute
- Recommended speed – 525 revolutions per minute

Belt conveyor
- Recommended flow – 10 bushels per minute
- Recommended speed – 6.28 linear feet per second

3.4.1 Brush Auger

Table 1 Brush Auger Treatments

	525 revolutions/minute	**300** revolutions/minute	**800** revolutions/minute
10 (bushels/minute)	√	√	√
4.5 (bushels/minute)	√		
12.5 (bushels/minute)	√		

3.4.2 Steel Auger

Table 2 Steel Auger Treatments

	525 revolutions/minute	**300** revolutions/minute	**800** revolutions/minute
10 (bushels/minute)	√	√	√
4.5 (bushels/minute)	√		
12.5 (bushels/minute)	√		

3.4.3 Plastic Cupped Auger

Table 3 Plastic Cupped Auger Treatments

	525 revolutions/minute	**300** revolutions/minute	**800** revolutions/minute
10 (bushels/minute)	√	√	√
4.5 (bushels/minute)	√		
12.5 (bushels/minute)	√		

3.4.4 Belt Conveyor

Table 4 Belt Conveyor Treatments

	6.28 linear feet/second	**5.23** linear feet/second	**800** revolutions/minute
10 (bushels/minute)	√	√	√
4.5 (bushels/minute)	√		
10 (bushels/minute) **Conveyed two times**	√		

3.5 Procedure

The following standard operating procedure was used for the treatment of the soybean seeds.

1. Transport System Setup
    a. Set up Conveyor at 35 degree angle, secure inlet end to make sure it can not tilt when loaded with seed.
    b. Place inlet end of the transport system under the feeding hopper.
    c. Place excess collection bin under auger spout, to catch any excess seed.

   d. Set conveyor speed to designated treatment speed using a tachometer.

2. Records

   Fill out data sheet with all required information

      a. Person collecting samples
      b. Date
      c. Time
      d. Seed tag information
      e. Room temperature
      f. Seed temperature
      g. Room humidity
      h. Seed moisture content
      i. Test number
         1. Flow
         2. Speed
         3. Repetition number

3. Seed Flow
   a. Calibrate hopper for mass flow rate
   b. Fill hopper from ProBox©

4. Testing
   a. Preparation
      a. Prepare collection bags, with appropriate labels
      b. Collect three 2 liter control samples from ProBox©
      c. Place control samples into labeled bags, and put into box for storage.
   b. Turn on transport system
   c. Open hopper to designated mass flow rate.
   d. Let seed flow through transport system reach steady state

e. Collect two liter sample from just below discharge and place into temporary storage container.
f. Collect 2^{nd} and 3^{rd} and 4^{th} repetition in same manner
g. Close seed gate
h. Allow conveyor to empty
i. Turn off conveyor
j. Bag seed samples
k. Place bagged samples into box, for safe keeping

5. Repeat above procedure with the next set of treatment conditions.

Chapter 4

Testing

4.1 Germination Testing

Germination testing is used to predict how seeds will develop when planted. There are many different types of testing that can be used to predict seed germination and assess seed quality. Some of the more common tests include: warm germination, cold germination, accelerated aging, and tetrazolium tests. Each test has different conditions and can reflect different planting conditions. Warm germination testing is required for all seeds prior to them being sold. Warm and cold germination testing are very common testing procedures that are standard in the seed industry. Using both tests together provides a better representation of the results, as the seeds are assessed in two different conditions.

4.1.1 Warm Germination Testing

Warm germination testing consists of placing 50 seeds onto a wet paper towel. A second wet paper towel is then placed over the seeds. The paper towels are then rolled up and placed into a controlled environment (77^{o} F) for a period of seven days. After seven days the paper towels are unwrapped and the seeds are analyzed and categorized as normal, abnormal, or dead. The categorization is dependent on whether the seed sprouted, had sufficient primary root growth, and was there sufficient secondary root growth. Seeds that did not sprout are classified as dead; seeds with poor primary or secondary root growth are classified as abnormal. Additionally, seeds with sufficient root growth with other external damage, such as cracked stems, or splits in the stem are classified as abnormal. Normal germination is considered when the seeds have a strong primary root and sufficient secondary roots, with no other external damage.

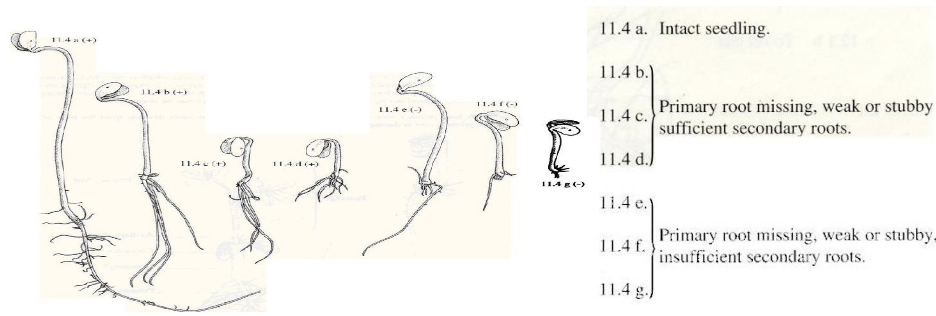

Figure 4.1 Seedling Evaluation Criteria

Figure 4.2 Before and After (Warm Germination)

4.1.2 Cold Germination Testing

Cold germination testing consists of placing seeds onto saturated Kimpak©. The seeds are then covered in a non-sterile sand soil mixture and placed into a controlled environment (10^{o} C) for a period of seven days. The seeds are then moved into another controlled environment (25^{o} C) for three additional days. The seeds are then analyzed and classified, normal germination is sprouted seeds with an established a solid root set. Abnormal seeds did not sprout or did not establish roots. Cold germination tests help give a representation of what germination would be like in less than ideal conditions as is common in most agricultural applications.

Figure 4.3 Cold Germination Results

Chapter 5

Analysis and Results

5.1 Analysis

Results from germination tests were analyzed using a one way Analysis of Variance or (ANOVA). The ANOVA results are used to look at the effect the treatment has created. By comparing the results of the ANOVA it can be determined if there is a statistically significant effect caused by the treatment. Thus, by comparing the treated seeds against the control, it can be determined if there is an effect on germination rates created by the different transport systems and operating conditions. A confidence interval of 90% was used in analyzing the data. The 90% interval is more appropriate for the smaller samples tested.

The creation of an interval plot allows for simple visual comparison of the results. The interval plot shows the relationship between the different treatments in graphical form as a mean point and range. The range is affected by the number of samples taken and the standard deviation. Examination of the plot for overlap between the treatments relates the significance of the results. If there is no overlap between the results then there is a statistical difference between treatments at the specified confidence interval.

Equation 5.1: Confidence Interval

$$Confidence\ Interval = \mu \pm \frac{2\sigma}{\sqrt{n}}$$

μ = Mean

σ = Standard deviation

n = Number of samples

5.2 Test Comparisons

The results from both the warm germination and cold germination tests were analyzed to determine if there was a difference between transport systems operating at recommended conditions. Each individual transport system was then compared against itself to determine how the operating conditions of the system affected the seed germination. All results were compared against the control, which received no treatment.

5.3 Warm Germination Results

The data from the warm germination tests showed that there was not a statistical difference in germination rates across the different transport system types. The means of the germination rates did trend towards an effect caused by the transport systems. The control germination rate mean was higher than that of the transport systems. The control and plastic auger had similar means, while the conveyor, steel, and brush auger show a similar mean to each other but decreased from the control mean rate.

Comparison of the individual transport systems at different operating conditions showed some instances of statistical significance. The steel and brush augers both showed significant decreases in germination rates versus the control when operating at a faster rotational speed than the recommended. Overall, there did not tend to be a significant effect on germination rates caused by the operating conditions of the individual transport systems.

The following interval plots are designated by speed and flow rate for the transport system type. A designation of 525-10 indicates a rotational speed of 525 revolutions per minute and mass flow rate of 10 bushels per minute. For the belt conveyor, the first number designates the linear speed of the belt in feet per second.

5.3.1 Transport System Comparison

Comparison of the different transport systems operating at the recommended speed and flow rate showed no statistical difference in warm germination rates.

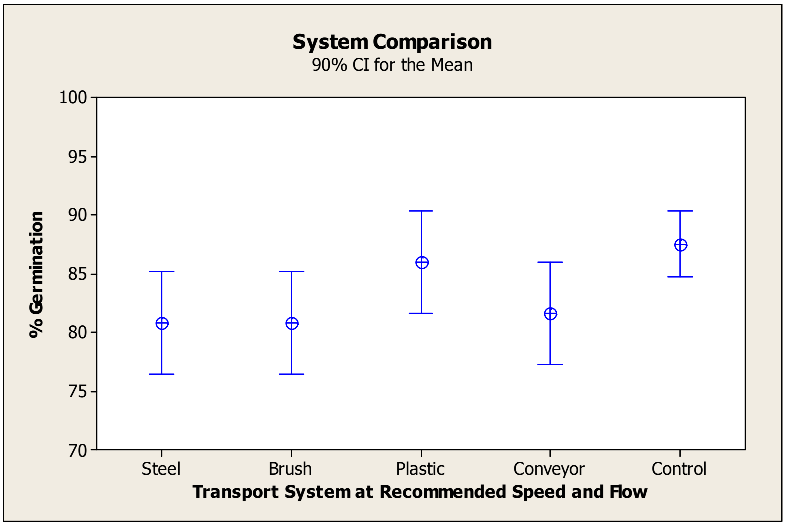

Figure 5.1 Interval Plot for Transport System Comparison

5.3.2 Belt Conveyor Analysis

The belt conveyor analysis showed no statistical difference between operating conditions.

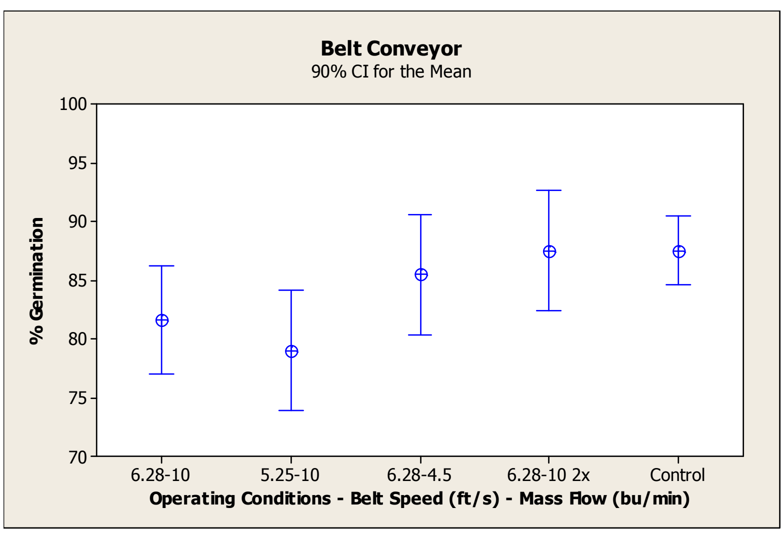

Figure 5.2 Interval Plot for Belt Conveyor Analysis

5.3.3 Steel Auger Analysis

The steel auger comparisons showed statistical difference in the germination rates for the 800 rpm auger condition as well as at the recommended settings.

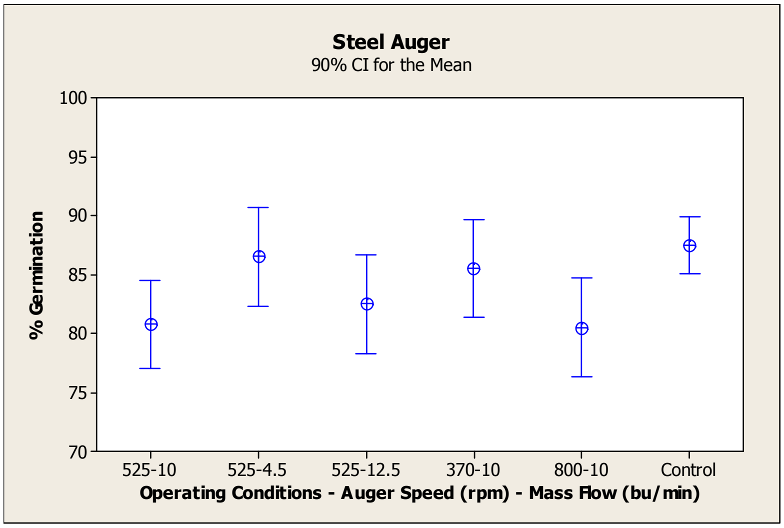

Figure 5.3 Interval Plot for Steel Auger Analysis (Warm Germination)

5.3.4 Brush Auger Analysis

The brush auger showed a statistical difference between the control and the 800 rpm auger condition and the recommended conditions.

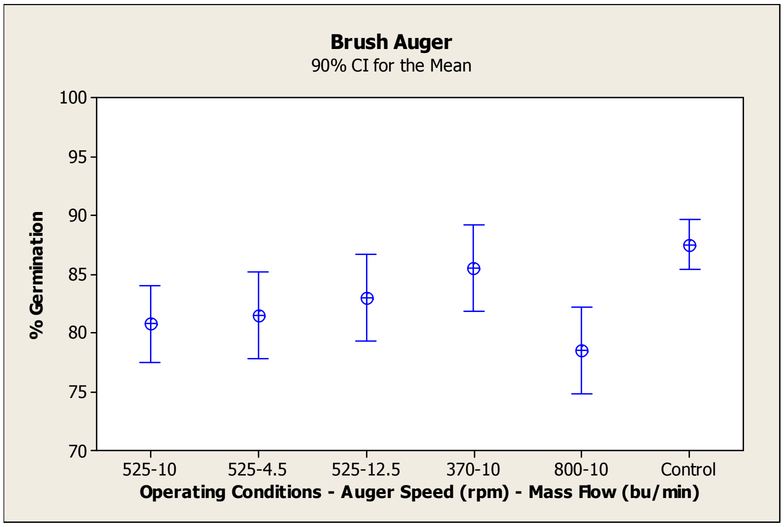

Figure 5.4 Interval Plot for Brush Auger Analysis (Warm Germination)

5.3.5 Plastic Auger Analysis

The plastic auger showed no statistical difference in germination rates between the treatments.

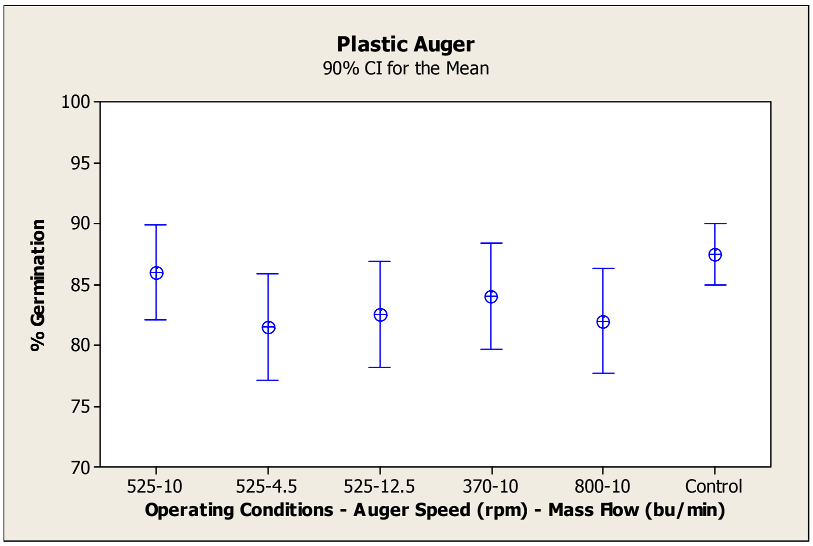

Figure 5.5 Interval Plot for Plastic Auger Analysis (Warm Germination)

5.4 Cold Germination Results

The data from the cold germination tests reinforced the warm germination test results. Again, there was not a statistical difference in germination rates across the different transport system types. The means of the germination rates did trend towards an effect caused by the transport systems. The control germination rate mean was higher than that of the transport systems.

Comparison of the individual transport systems at different operating conditions showed no statistical significance relating to germination rates. The control mean was again higher than that of the treated seeds, but with no general trend on the best operating conditions for the transport system.

As with the warm germination results, the following interval plots are designated by speed and flow rate for the transport system type. A designation of 525-10 indicates a rotational speed of 525 revolutions per minute and mass flow rate of 10 bushels per minute. For the belt conveyor, the first number designates the linear speed of the belt in feet per second.

5.4.1 Transport System Comparison

The cold germination results showed no statistical difference in germination rates between the transport systems operating at recommended speed and flow rate.

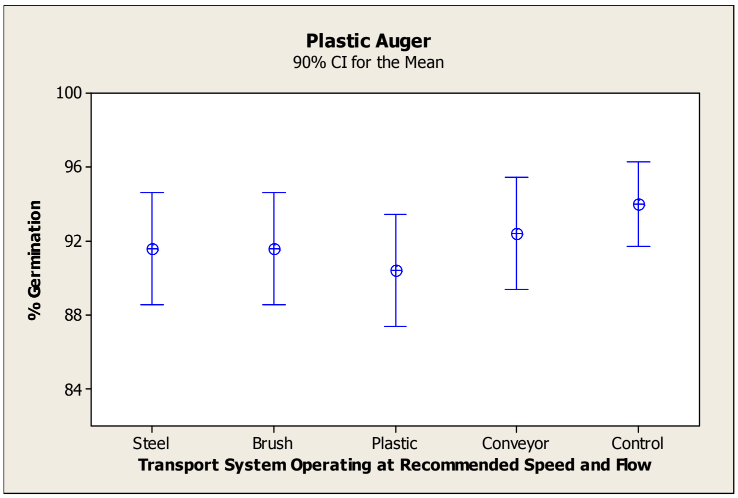

Figure 5.6 Interval Plot for Transport System Comparison (Cold Germination)

5.4.2 Belt Conveyor Analysis

The belt conveyor showed no statistical difference between treatments.

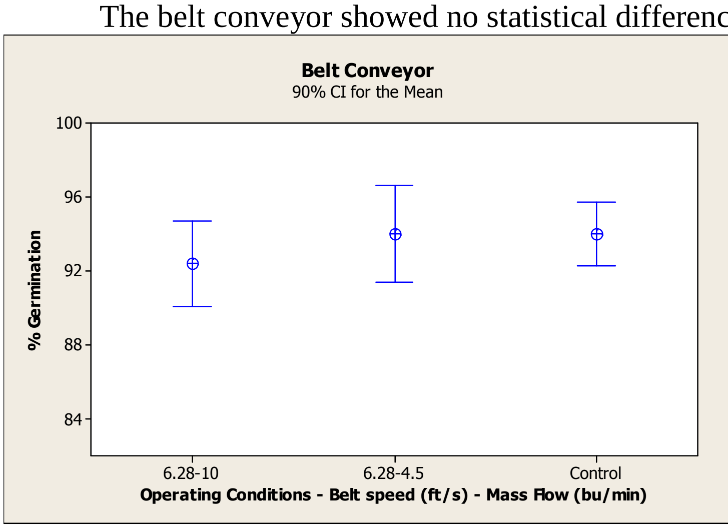

Figure 5.7 Interval Plot for Belt Conveyor Analysis (Cold Germination)

5.4.3 Steel Auger Analysis

The steel auger showed a statistical difference between the control and the auger operating at 370 revolutions per minute.

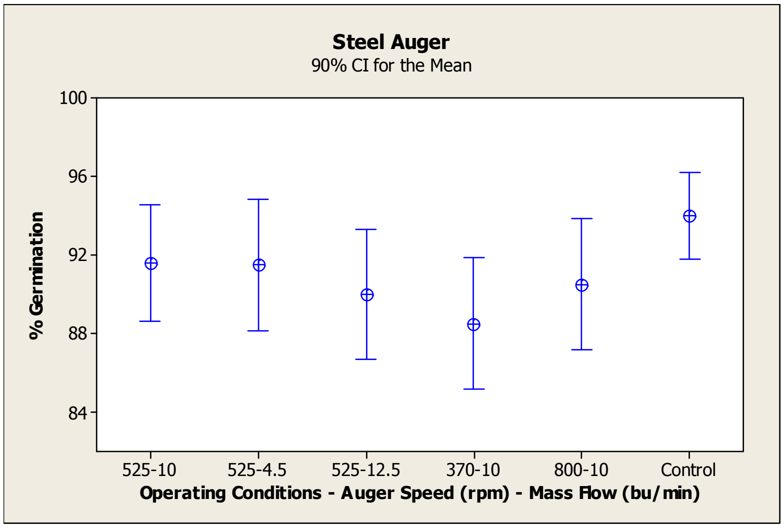

Figure 5.8 Interval Plot for Steel Auger Analysis (Cold Germination)

5.4.4 Brush Auger Analysis

The brush auger analysis showed no statistical difference between the control sample and the different treatment conditions.

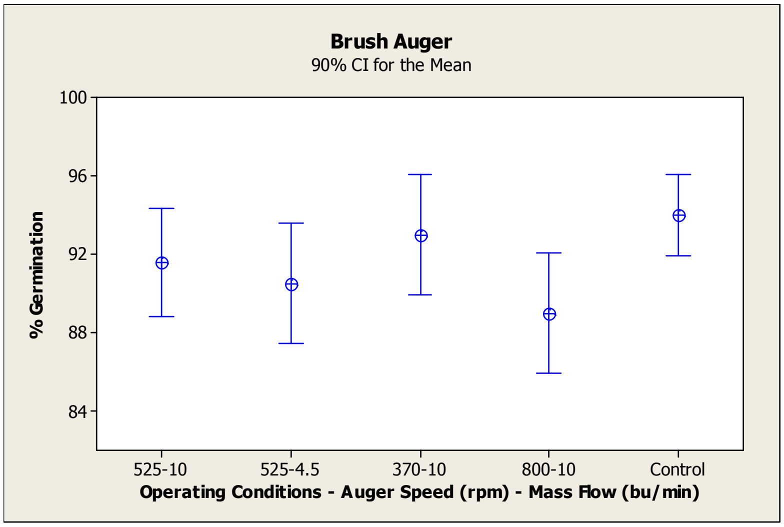

Figure 5.9 Interval Plot for Brush Auger Analysis (Cold Germination)

5.4.5 Plastic Cupped Auger Analysis

The plastic auger showed a statistical difference between the control and the treatment of recommended speed and low flow.

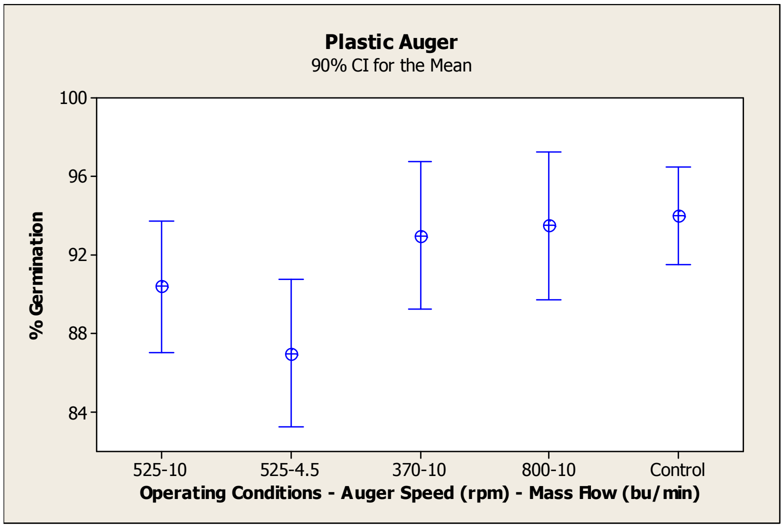

Figure 5.10 Interval Plot for Plastic Auger Analysis (Cold Germination)

Chapter 6

Conclusion and Recommendations

6.1 Conclusions

The results of this research are preliminary in that the sample sizes were small (50 seed samples), and only four or five repetitions were completed for each treatment. The small number of seeds tested can lead to skewed results, if a proportionate number of damaged seeds are not pulled from the sample, but rather a larger or smaller number of damaged seeds are tested.

A trend does seem to exist in the means of the treatments. There does seem to be damage to the seeds after having passed through the transport system, indicating that with increased sample size and repetition there could be enough data to show a statistically significant effect relating to germination rates.

In order to draw definitive conclusions regarding the transport systems more testing needs to be completed to ensure that the preliminary results from this experiment are consistent over a larger sample size. By assuming the means are accurate, an estimate of the total number of samples needed to show significance can be estimated. Increasing the number of repetitions from 4 to 10 should allow for the data to show significance if there is a true effect on the germination rates.

6.2 Summary of Results

Table A. 1 Summary of Results

Statistical Difference vs. Control

Transport System	*Belt Conveyor*	*Steel Auger*	*Brush Auger*	*Plastic Auger*
Warm Germination	No	No	No	No
Cold Germination	No	No	No	No

Belt Conveyor	*6.28-10*	*5.25-10*	*6.28-4.5*	*6.28-10 x2*
Warm Germination	No	No	No	No
Cold Germination	No	No	No	No

Steel Auger	*525-10*	*525-4.5*	*525-12.5*	*370-10*	*800-10*
Warm Germination	**Yes**	No	No	No	**Yes**
Cold Germination	No	No	No	**Yes**	No

Brush Auger	*525-10*	*525-4.5*	*525-12.5*	*370-10*	*800-10*
Warm Germination	**Yes**	No	No	No	**Yes**
Cold Germination	No	No	No	No	No

Plastic Auger	*525-10*	*525-4.5*	*525-12.5*	*370-10*	*800-10*
Warm Germination	No	No	No	No	No
Cold Germination	No	**Yes**	No	No	No

6.3 Research Implications

Further research into this area, could be conducted to further solidify the results of these tests. Larger sample sizes would be necessary to garner more comprehensive results.

Another consideration would be to look at the effect of the outlet conditions of the transport systems. Significant damage could be created when seeds contact the outlet of the transport system either coming off the end of the conveyor belt or out the end of the auger system.

The effect of the damage from the system as well as the effectiveness of the application of seed treatments, for example, inoculants being applied at the inlet of the transport system could also be explored. The mixing or spraying system at the inlet in conjunction with the damage caused by the transport system could affect germination and vigor. A poor combination of inoculant application and seed damage could be more costly for seed growers than just damage from the system alone.

Chapter 7

Warm and Cold Germination Raw Data

All numbers in tables are normally germinated seeds out of a total of 50 seeds tested.

Table 5

Control Data - Warm Germination

Repetition1	45
Repetition 2	46
Repetition 3	44
Repetition 4	41
Repetition 5	43
Repetition 6	39
Repetition 7	42
Repetition 8	46
Repetition 9	44
Repetition 10	46
Repetition 11	43
Repetition 12	46

Table 6

Control Data - Warm Germination

Repetition1	47
Repetition 2	47
Repetition 3	45
Repetition 4	49
Repetition 5	45
Repetition 6	47
Repetition 7	47
Repetition 8	47
Repetition 9	49
Repetition 10	-
Repetition 11	-
Repetition 12	-

Table 7

System Comparison - Warm Germination

	Belt Conveyor	Steel Auger	Brush Auger	Plastic Auger
Repetition1	38	42	42	45
Repetition 2	43	41	40	45
Repetition 3	42	44	40	41
Repetition 4	35	41	42	44
Repetition 5	46	34	38	40

Table 8

System Comparison - Cold Germination

	Belt Conveyor	Steel Auger	Brush Auger	Plastic Auger
Repetition1	46	48	46	44
Repetition 2	47	48	47	45
Repetition 3	49	44	48	42
Repetition 4	44	42	44	48
Repetition 5	45	47	44	47

Table 9

Belt Conveyor - Warm Germination

	6.28-10	5.25-10	6.28-4.5	6.28-10 2x
Repetition1	38	45	47	44
Repetition 2	43	36	43	45
Repetition 3	42	39	39	44
Repetition 4	35	38	42	42
Repetition 5	46	-	-	-

Table 10

Belt Conveyor - Cold Germination

	6.28-10	5.25-10	6.28-4.5	6.28-10 2x
Repetition1	46	-	47	-
Repetition 2	47	-	48	-
Repetition 3	49	-	46	-
Repetition 4	44	-	47	-
Repetition 5	45	-	-	-

Table 11

Steel Auger - Warm Germination

	525-10	525-4.5	525-12	370-10	800-10
Repetition1	42	44	41	41	40
Repetition 2	41	43	45	44	38
Repetition 3	44	43	42	44	42
Repetition 4	41	43	37	42	41
Repetition 5	34	-	-	-	-

Table 12

Steel Auger - Cold Germination

	525-10	525-4.5	525-12	370-10	800-10
Repetition1	48	47	45	42	44
Repetition 2	48	46	48	45	45
Repetition 3	44	45	42	43	48
Repetition 4	42	45	45	47	44
Repetition 5	47	-	-	-	-

Table 13

Brush Auger - Warm Germination

	525-10	525-4.5	525-12	370-10	800-10
Repetition1	42	39	40	40	40
Repetition 2	40	42	43	42	38
Repetition 3	40	44	42	44	42
Repetition 4	42	38	41	45	37
Repetition 5	38	-	-	-	-

Table 14

Brush Auger - Cold Germination

	525-10	525-4.5	525-12	370-10	800-10
Repetition1	46	46	-	45	47
Repetition 2	47	45	-	45	46
Repetition 3	48	43	-	48	41
Repetition 4	44	47	-	48	44
Repetition 5	44	-	-	-	-

Table 15

Plastic Auger - Warm Germination

	525-10	525-4.5	525-12	370-10	800-10
Repetition1	45	39	40	43	40
Repetition 2	45	42	43	41	38
Repetition 3	41	44	42	42	42
Repetition 4	44	38	41	42	37
Repetition 5	40	-	-	-	-

Table 16

Plastic Auger - Cold Germination

	525-10	525-4.5	525-12	370-10	800-10
Repetition1	44	38	-	46	47
Repetition 2	45	45	-	47	48
Repetition 3	42	47	-	45	44
Repetition 4	48	44	-	48	48
Repetition 5	47	-	-	-	-

7.1 Warm Germination Results

7.1.1 Transport System Comparison

One-way ANOVA: Steel, Brush, Plastic, Conveyor, Control

```
Source   DF      SS    MS     F      P
Factor    4   296.2  74.1  2.26  0.089
Error    27   885.8  32.8
Total    31  1182.0

S = 5.728   R-Sq = 25.06%   R-Sq(adj) = 13.96%


                             Individual 90% CIs For Mean Based on
                             Pooled StDev
Level      N    Mean  StDev   --+---------+---------+---------+-------
Steel      5  80.800  7.563   (------------*-----------)
Brush      5  80.800  3.347   (------------*-----------)
Plastic    5  86.000  4.690                  (------------*-----------)
Conveyor   5  81.600  8.649      (-----------*------------)
Control   12  87.500  4.523                           (-------*-------)
                              --+---------+---------+---------+-------
                             77.0      80.5      84.0      87.5

Pooled StDev = 5.728
```

7.1.2 Belt Conveyor Analysis

One-way ANOVA: 6.28-10, 5.25-10, 6.28-4.5, 6.28-10 2x, Control

```
Source   DF      SS    MS     F      P
Factor    4   302.8  75.7  2.13  0.109
Error    24   854.2  35.6
Total    28  1157.0

S = 5.966   R-Sq = 26.17%   R-Sq(adj) = 13.86%


                               Individual 90% CIs For Mean Based on
                               Pooled StDev
Level        N    Mean  StDev   --+---------+---------+---------+-------
6.28-10      5  81.600  8.649         (--------*--------)
5.25-10      4  79.000  7.746   (---------*---------)
6.28-4.5     4  85.500  6.608                (---------*---------)
6.28-10 2x   4  87.500  2.517                    (---------*---------)
Control     12  87.500  4.523                        (-----*-----)
                                --+---------+---------+---------+-------
                               75.0      80.0      85.0      90.0

Pooled StDev = 5.966
```

7.1.3 Steel Auger Analysis

One-way ANOVA: 525-10, 525-4.5, 525-12.5, 370-10, 800-10, Control

```
Source  DF     SS    MS     F      P
Factor   5  275.5  55.1  2.29  0.074
Error   27  649.8  24.1
Total   32  925.3

S = 4.906   R-Sq = 29.78%   R-Sq(adj) = 16.77%


                             Individual 90% CIs For Mean Based on
                             Pooled StDev
Level      N    Mean  StDev  ---------+---------+---------+---------+
525-10     5  80.800  7.563    (--------*--------)
525-4.5    4  86.500  1.000                 (---------*----------)
525-12.5   4  82.500  6.608       (---------*----------)
370-10     4  85.500  3.000              (----------*---------)
800-10     4  80.500  3.416  (---------*----------)
Control   12  87.500  4.523                        (-----*-----)
                             ---------+---------+---------+---------+
                                  80.0      84.0      88.0      92.0

Pooled StDev = 4.906
```

7.1.4 Brush Auger Analysis

One-way ANOVA: 525-10, 525-4.5, 525-12.5, 370-10, 800-10, Control

```
Source  DF     SS    MS     F      P
Factor   5  356.7  71.3  3.86  0.009
Error   27  498.8  18.5
Total   32  855.5

S = 4.298   R-Sq = 41.70%   R-Sq(adj) = 30.90%


                             Individual 90% CIs For Mean Based on
                             Pooled StDev
Level      N    Mean  StDev  ---+---------+---------+---------+------
525-10     5  80.800  3.347         (-------*-------)
525-4.5    4  81.500  5.508          (--------*--------)
525-12.5   4  83.000  2.582             (---------*--------)
370-10     4  85.500  4.435                    (--------*--------)
800-10     4  78.500  4.435  (--------*--------)
Control   12  87.500  4.523                            (-----*----)
                             ---+---------+---------+---------+------
                             76.0      80.0      84.0      88.0

Pooled StDev = 4.298
```

7.1.5 Plastic Auger Analysis

One-way ANOVA: 525-10, 525-4.5, 525-12.5, 370-10, 800-10, Control

```
Source  DF     SS    MS     F      P
Factor   5  193.2  38.6  1.48  0.228
Error   27  703.0  26.0
Total   32  896.2

S = 5.103   R-Sq = 21.56%   R-Sq(adj) = 7.04%


                             Individual 90% CIs For Mean Based on Pooled
                             StDev
Level      N    Mean  StDev     +---------+---------+---------+---------
525-10     5  86.000  4.690                   (----------*----------)
525-4.5    4  81.500  9.292     (------------*-----------)
525-12.5   4  82.500  5.745        (------------*-----------)
370-10     4  84.000  1.633             (-----------*-----------)
800-10     4  82.000  2.828       (-----------*------------)
Control   12  87.500  4.523                            (------*------)
                                +---------+---------+---------+---------
                             77.0      80.5      84.0      87.5

Pooled StDev = 5.103
```

A.2 Cold Germination Results

7.1.1 Transport System Comparison

One-way ANOVA: Steel, Brush, Plastic, Conveyor, Control

```
Source  DF     SS    MS     F      P
Factor   4   49.0  12.2  0.77  0.554
Error   24  380.8  15.9
Total   28  429.8

S = 3.983   R-Sq = 11.40%   R-Sq(adj) = 0.00%


                            Individual 90% CIs For Mean Based on
                            Pooled StDev
Level     N    Mean  StDev    -+---------+---------+---------+--------
Steel     5  91.600  5.367         (-----------*------------)
Brush     5  91.600  3.578         (-----------*------------)
Plastic   5  90.400  4.775    (------------*-----------)
Conveyor  5  92.400  3.847            (------------*-----------)
Control   9  94.000  2.828                      (--------*--------)
                              -+---------+---------+---------+--------
                            87.5      90.0      92.5      95.0

Pooled StDev = 3.983
```

7.1.2 Belt Conveyor Analysis

One-way ANOVA: 6.28-10, 6.28-4.5, Control

```
Source  DF      SS    MS     F      P
Factor   2    9.24  4.62  0.53  0.600
Error   15  131.20  8.75
Total   17  140.44

S = 2.957   R-Sq = 6.58%   R-Sq(adj) = 0.00%


                            Individual 90% CIs For Mean Based on Pooled
                            StDev
Level      N    Mean  StDev    +---------+---------+---------+---------
6.28-10    5  92.400  3.847    (-----------*-----------)
6.28-4.5   4  94.000  1.633           (------------*------------)
Control    9  94.000  2.828               (--------*--------)
                               +---------+---------+---------+---------
                            90.0      92.0      94.0      96.0

Pooled StDev = 2.957
```

7.1.3 Steel Auger Analysis

One-way ANOVA: 525-10, 525-4.5, 525-12.5, 370-10, 800-10, Control

```
Source  DF     SS    MS     F      P
Factor   5  105.3  21.1  1.39  0.264
Error   24  364.2  15.2
Total   29  469.5

S = 3.896   R-Sq = 22.42%   R-Sq(adj) = 6.26%


                            Individual 90% CIs For Mean Based on
                            Pooled StDev
Level      N    Mean  StDev  ------+---------+---------+---------+---
525-10     5  91.600  5.367            (---------*---------)
525-4.5    4  91.500  1.915           (----------*----------)
525-12.5   4  90.000  4.899      (----------*----------)
370-10     4  88.500  4.435  (----------*----------)
800-10     4  90.500  3.786        (----------*----------)
Control    9  94.000  2.828                      (------*-------)
                             ------+---------+---------+---------+---
                                87.0      90.0      93.0      96.0

Pooled StDev = 3.896
```

7.1.4 Brush Auger Analysis

One-way ANOVA: 525-10, 525-4.5, 370-10, 800-10, Control

```
Source  DF     SS    MS     F      P
Factor   4   85.6  21.4  1.66  0.196
Error   21  270.2  12.9
Total   25  355.8

S = 3.587   R-Sq = 24.07%   R-Sq(adj) = 9.61%


                           Individual 90% CIs For Mean Based on
                           Pooled StDev
Level    N    Mean  StDev  ----+---------+---------+---------+-----
525-10   5  91.600  3.578            (--------*---------)
525-4.5  4  90.500  3.416       (----------*---------)
370-10   4  93.000  3.464                (---------*---------)
800-10   4  89.000  5.292  (----------*---------)
Control  9  94.000  2.828                      (------*------)
                           ----+---------+---------+---------+-----
                            87.0      90.0      93.0      96.0

Pooled StDev = 3.587
```

7.1.5 Plastic Auger Analysis

One-way ANOVA: 525-10, 525-4.5, 370-10, 800-10, Control

```
Source  DF     SS    MS     F      P
Factor   4  161.8  40.4  2.13  0.112
Error   21  398.2  19.0
Total   25  560.0

S = 4.355   R-Sq = 28.89%   R-Sq(adj) = 15.35%


                           Individual 90% CIs For Mean Based on
                           Pooled StDev
Level    N    Mean  StDev   --+---------+---------+---------+-------
525-10   5  90.400  4.775              (--------*---------)
525-4.5  4  87.000  7.746   (----------*---------)
370-10   4  93.000  2.582                    (----------*---------)
800-10   4  93.500  3.786                     (----------*----------)
Control  9  94.000  2.828                          (-------*------)
                            --+---------+---------+---------+-------
                           84.0      87.5      91.0      94.5

Pooled StDev = 4.355
```

Bibliography

Association of Official Seed Analysts. “Seedling Evaluation Handbook”. 1992.

Montgomery, D.C. and Peck, E. A. (1982). *Introduction to Linear Regression Analysis*. John Wiley & Sons.

National Agricultural Statistics Service (NASS). “Acreage”. Updated June 2004. Retrieved 15 March 2006. <http://usda.mannlib.cornell.edu/reports/nassr/field/pcp-bba/acrg0604.pdf#search='acres%20planted%20to%20soybean%20in%20the%20USA'>.

Wellman Seeds, Inc. Retrieved 1 April 2006. < www.wellmanseeds.com/soybeans.php?rid=8>.